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**Abstract**

This study investigates the geological evolution of the Iranian plateau in relation to the dynamics of the Proto-Tethys Ocean and its significant impact on regional tectonics. The North Alborz fault, characterized by medium to high-pressure metamorphic rocks, is proposed as the Proto-Tethys suture, providing crucial evidence of the ocean's presence and influence in the region. Comparative data from Turkey and China, including ophiolitic remnants and high-pressure metamorphic complexes, suggest a shared tectonic history among these regions, highlighting the interconnectedness of their geological past. The Yangtze Block in China also exhibits evidence of Proto-Tethys dynamics, with significant subduction processes and comparable sedimentary records, further supporting the idea of a common tectonic narrative. Our findings reveal a paleogeodynamic framework featuring three adjacent oceanic bodies, including the Proto-Tethys in northern Iran and two back-arcs to the south, between 580-520 Ma. This time period is critical in understanding the evolution of the region, as it marks a significant phase of tectonic activity and continental assembly. The shared geodynamic narrative that emerges from our research highlights the interconnectedness of these tectonic settings and their role in continental assembly, providing valuable insights into the complex processes that have shaped the Earth's surface over millions of years. By examining the geological histories of Iran, Turkey, and China, we can gain a deeper understanding of Earth's tectonic evolution, informing future resource exploration and environmental assessments. Furthermore, this study demonstrates the importance of considering the regional tectonic context in understanding the geological evolution of a particular area, and how this can be applied to other regions with similar tectonic settings. The comparative analysis of these regions also underscores the value of interdisciplinary research, combining geological, geophysical, and geochemical data to reconstruct the Earth's history and better understand the complex processes that have shaped our planet.

**Keywords:** Proto-Tethys Ocean, Iranian Plateau, Tectonics, Metamorphism, Geological Evolution

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# Proto-Tethys and Iranian Geology: A Precambrian to Paleozoic Review

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# Proto-Tethys and Iranian Geology: A Precambrian to Paleozoic Review

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# Proto-Tethys and Iranian Geology: A Precambrian to Paleozoic Review


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## Extended Abstract

This study examines the geological evolution of the Iranian plateau in relation to the Proto-Tethys Ocean's dynamics and its impact on regional tectonics. The North Alborz fault, marked by medium to high-pressure metamorphic rocks, including those from the Gasht complex, is proposed as the suture of the Proto-Tethys. Similar geological formations in Turkey and China provide comparative data, with Turkey's ophiolitic remnants and high-pressure metamorphic complexes reflecting a shared tectonic history with Iran. China's Yangtze Block also shows evidence of Proto-Tethys dynamics, with significant subduction processes and comparable sedimentary records.

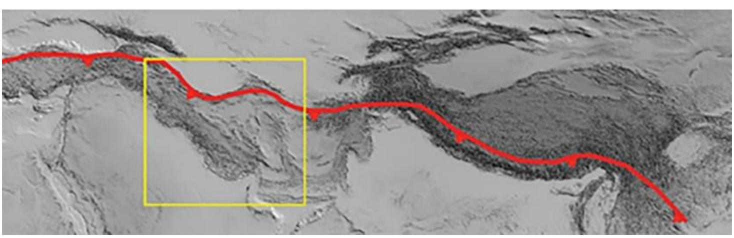
Our findings indicate a paleo-geodynamic framework, characterized by three adjacent oceanic bodies, including the Proto-Tethys in northern Iran and two back-arcs to the south, between approximately 580-520 Ma. This shared geodynamic narrative highlights the interconnectedness of these tectonic settings and the broader patterns of continental assembly influenced by ancient oceanic processes. By understanding the relationship between the geological histories of Iran, Turkey, and China, we can gain valuable insights into Earth's tectonic evolution, with implications for future resource exploration and environmental assessments. The paleo-geodynamic

framework proposed in this study has significant implications for our understanding of the regional tectonic evolution, particularly in the context of the Iranian plateau's formation. The presence of medium to high-pressure metamorphic rocks along the North Alborz fault, coupled with similar formations in Turkey and China, suggests a complex interplay between the Proto-Tethys Ocean and the surrounding continental masses. The Gasht complex, with its unique metamorphic signature, provides a critical window into the subduction processes that characterized this ancient oceanic system.

Further analysis of the sedimentary records and ophiolitic remnants in Turkey and China reveals a shared tectonic history, with evidence of significant subduction and continental collision. The Yangtze Block in China, in particular, exhibits a similar pattern of Proto-Tethys dynamics, with substantial sedimentary deposits and metamorphic complexes that reflect the region's complex geological evolution. By integrating these findings with existing data on the Iranian plateau, we can reconstruct a more comprehensive narrative of the region's tectonic history, shedding light on the intricate relationships between ancient oceanic processes and continental assembly.

The identification of three adjacent oceanic bodies, including the Proto-Tethys, during the period of approximately 580-520 Ma, highlights the dynamic nature of the Earth's surface during this time. The back-arc basins to the south of the Proto-Tethys, in particular, played a critical role in shaping the regional tectonic landscape, with significant implications for our understanding of the Earth's mantle dynamics and crustal evolution. By elucidating the relationships between these ancient oceanic bodies and the surrounding continental masses, we can gain a deeper understanding of the processes that have shaped our planet's surface over millions of years, ultimately informing our approaches to resource exploration, environmental assessment, and geological hazard mitigation.

**Keywords:** Proto-Tethys Ocean, Iranian Plateau, Tectonics, Metamorphism, Geological evolution



A general view of Proto-Tethys suture from Turkey to souteast Asia and Iranain plateau along with, yellow rectangle shows iranian tretory as study area.

## Résumé Étendu

Cette étude examine l'évolution géologique du plateau iranien en relation avec la dynamique de l'océan Proto-Téthys et son impact sur la tectonique régionale. La faille de l'Alborz Nord, marquée par des roches métamorphiques de pression moyenne à élevée, y compris celles du complexe de Gasht, est proposée comme la suture du Proto-Téthys. Des formations géologiques similaires en Turquie et en Chine fournissent des données comparatives, avec les vestiges ophiolitiques et les complexes métamorphiques de haute pression de la Turquie reflétant une histoire tectonique partagée avec l'Iran. Le bloc du Yangtsé en Chine montre également des preuves de la dynamique du Proto-Téthys, avec des processus de subduction significatifs et des enregistrements sédimentaires comparables.

Nos résultats indiquent un cadre paléogéodynamique, caractérisé par trois corps océaniques adjacents, dont le Proto-Téthys dans le nord de l'Iran et deux arcs arrière au sud, entre environ 580-520 Ma. Ce récit géodynamique partagé met en évidence l'interconnexion de ces contextes tectoniques et les schémas plus larges d'assemblage continental influencés par les processus océaniques anciens. En comprenant la relation entre les histoires géologiques de l'Iran, de la Turquie et de la Chine, nous pouvons

obtenir des informations précieuses sur l'évolution tectonique de la Terre, avec des implications pour l'exploration future des ressources et les évaluations environnementales.

Le cadre paléo-géodynamique proposé dans cette étude a des implications significatives pour notre compréhension de l'évolution tectonique régionale, en particulier dans le contexte de la formation du plateau iranien. La présence de roches métamorphiques de pression moyenne à élevée le long de la faille de l'Alborz Nord, couplée à des formations similaires en Turquie et en Chine, suggère une interaction complexe entre l'océan Proto-Téthys et les masses continentales environnantes. Le complexe de Gasht, avec sa signature métamorphique unique, fournit une fenêtre critique sur les processus de subduction qui ont caractérisé ce système océanique ancien.

Une analyse plus approfondie des enregistrements sédimentaires et des vestiges ophiolitiques en Turquie et en Chine révèle une histoire tectonique partagée, avec des preuves de subduction significative et de collision continentale. Le bloc du Yangtsé en Chine, en particulier, présente un schéma similaire de dynamique du Proto-Téthys, avec des dépôts sédimentaires substantiels et des complexes métamorphiques qui reflètent l'évolution géologique complexe de la région. En intégrant ces découvertes

avec les données existantes sur le plateau iranien, nous pouvons reconstruire un récit plus complet de l'histoire tectonique de la région, mettant en lumière les relations complexes entre les processus océaniques anciens et l'assemblage continental.

L'identification de trois corps océaniques adjacents, y compris le Proto-Téthys, pendant la période d'environ 580-520 Ma, met en évidence la nature dynamique de la surface de la Terre à cette époque. Les bassins arrière au sud du Proto-Téthys, en particulier, ont joué un rôle crucial dans la formation du paysage tectonique régional, avec des implications significatives pour notre compréhension de la dynamique du manteau terrestre et de l'évolution de la croûte. En élucidant les relations entre ces corps océaniques anciens et les masses continentales environnantes, nous pouvons approfondir notre compréhension des processus qui ont façonné la surface de notre planète au cours de millions d'années, informant finalement nos approches en matière d'exploration des ressources, d'évaluation environnementale et de mitigation des risques géologiques.

**Mots-clés :** Océan Proto-Téthys, Plateau iranien, Tectonique, Métamorphisme, Évolution géologique

## Critic and review to the Tethys

The Proto-Tethys Ocean existed from the late Ediacaran period through the Carboniferous period. It played a significant role in the geological evolution of Earth during that time, preceding the formation of the modern Tethys Ocean. This ancient ocean basin contributed to the shaping of continents, ocean circulation patterns, and global climate dynamics during the Paleozoic era.

The Proto-Tethys and Paleo-Tethys oceans are two distinct stages in the evolution of the Tethys Ocean system:

**1. Proto-Tethys:**

- Time Period: Late Ediacaran to Carboniferous (approximately 570 to 300 million years ago).

- Location: Initially located between the supercontinents of Laurentia and Gondwana.

- Characteristics: Proto-Tethys was an early precursor to the Tethys Ocean system. It formed during the breakup of the supercontinent Rodinia and continued to develop as Pangaea began to assemble. Proto-Tethys was relatively narrow and elongated, with its initial opening resulting from the separation of landmasses.

Geological Significance: Proto-Tethys played a role in the dispersal of continents and the formation of new oceanic crust. Its evolution contributed to the configuration of landmasses and ocean basins during the early stages of the Paleozoic era. The Proto-Tethys Ocean, on the other hand, was an earlier oceanic basin that existed during the late Precambrian to Carboniferous periods, preceding the formation of the Paleo-Tethys Ocean. The closure of the Proto-Tethys Ocean and the amalgamation of continental fragments along its margins played a significant role in the tectonic evolution of the region, but it is not directly associated with the Cimmerian orogeny.

The Iranian Plateau is known for its complex geology, including remnants of the Proto-Tethys Ocean and suture zones resulting from the closure of ancient ocean basins. Here are some notable areas in the Iranian Plateau associated with suture zones and remnants of the Proto-Tethys:

1. Zagros Suture Zone:

- The Zagros Mountains in southwestern Iran is a major suture zone formed by the closure of the Neo-Tethys Ocean during the Cenozoic era.

- While the Zagros Mountains primarily represent the closure of the Neo-Tethys, they also contain remnants and tectonic features related to the earlier Proto-Tethys.

- In the Zagros region, you may find ophiolite complexes, melange zones, and other geological features associated with the closure of ancient ocean basins, including the Proto-Tethys.

2. Sanandaj- Sirjan Zone:

- The Sanandaj- Sirjan Zone is a significant tectonic zone in western Iran that represents the suture between the Iranian Plateau and the Arabian Plate.

- This zone contains a complex assemblage of rocks, including ophiolites, blueschists, and other oceanic remnants, which are interpreted as remnants of the Proto-Tethys Ocean.

3. Alborz Mountains:

- The Alborz Mountains in northern Iran is another area where remnants of the Proto-Tethys can be found.

- The Alborz region contains ophiolite complexes and other geological features associated with the closure of ancient ocean basins during the Paleozoic and Mesozoic eras. The North Alborz Fault, located in the Alborz Mountain range of northern Iran, is indeed a significant geological feature, but it is not typically considered a suture zone related to the closure of the Proto-Tethys

Ocean. Instead, the North Alborz Fault is primarily associated with more recent tectonic activity related to the collision between the Arabian Plate and the Eurasian Plate.

However, within the Alborz Mountain range, there are indeed geological features that are associated with the closure of the Proto-Tethys Ocean during earlier geological periods. These features include ophiolite complexes, which represent remnants of oceanic crust formed in the Proto-Tethys Ocean and subsequently accreted onto the continental margin during subduction and collision processes.

While the North Alborz Fault may not directly represent a suture zone related to the closure of the Proto-Tethys Ocean, it does play a role in accommodating tectonic stresses associated with the ongoing collision between the Arabian Plate and the Eurasian Plate. The fault system is part of the broader tectonic framework of the Alborz Mountain range and reflects the complex tectonic history of the region. The Gasht Complex, characterized by high-grade metamorphic rocks with an age older than 530 million years, is indeed significant in the context of the geological evolution of the Alborz Mountain range, particularly in proximity to the North Alborz Fault. Here's how we can interpret this in relation to the tectonic history of the region:

1. Metamorphic Rocks and Age:

- The presence of high-grade metamorphic rocks within the Gasht Complex suggests that these rocks have undergone significant tectonic and thermal events in the past.

- Metamorphic rocks typically form under conditions of high temperature and pressure, often associated with tectonic processes such as subduction, collision, or crustal thickening.

- The age of these metamorphic rocks, older than 530 million years, indicates that they likely formed during Precambrian or early Paleozoic tectonic events.

2. Proximity to the North Alborz Fault:

- The North Alborz Fault is a major tectonic feature in the Alborz Mountain range, accommodating the tectonic stresses associated with the ongoing collision between the Arabian Plate and the Eurasian Plate.

- While the North Alborz Fault may primarily represent more recent tectonic activity related to the collision between these plates, its proximity to the Gasht Complex suggests a possible connection to earlier tectonic events.

3. Interpretation:

- The presence of high-grade metamorphic rocks with an age older than 530 million years close to the North Alborz Fault implies that these rocks may have been part of the ancient continental margin or oceanic crust associated with the closure of the Proto-Tethys Ocean.

- It's possible that these rocks were subjected to intense tectonic and metamorphic processes during the closure of the Proto-Tethys Ocean and subsequent collision and accretion events along the northern margin of Gondwana.

- While the Gasht Complex, itself may not represent a suture zone in the strictest sense, its geological characteristics and age provide valuable insights into the tectonic history and evolution of the Alborz Mountain range, including its connections to the closure of ancient ocean basins like the Proto-Tethys.

In summary, the Gasht Complex's presence of high-grade metamorphic rocks with an age older than 530 million years in proximity to the North Alborz Fault suggests a complex tectonic history involving the closure of ancient oceanic basins like the Proto-Tethys, as well as subsequent tectonic events associated with plate collision and mountain building.

4. Central Iranian Plateau:

- In central Iran, especially in areas such as Yazd and Kerman, there are exposures of ophiolitic rocks and associated metamorphic complexes that are considered remnants of the Proto-Tethys Ocean.

- These areas provide insights into the tectonic history and evolution of the Iranian Plateau during the Paleozoic and Mesozoic eras.

These are just a few examples of areas within the Iranian Plateau where remnants of the Proto-Tethys can be observed. The geology of the region is highly complex and continues to be the subject of active research in the fields of geology and tectonics.

**2. Paleo-Tethys:**

- Time Period: Late Paleozoic to Mesozoic (approximately 300 to 140 million years ago).

- Location: Formed as Pangaea continued to break apart, located between the newly forming continents of Laurasia and Gondwana.

- Characteristics: Paleo-Tethys was wider and more expansive compared to Proto-Tethys. It resulted from the ongoing breakup of Pangaea and the opening of ocean basins between Laurasia and Gondwana. Paleo-Tethys was characterized by extensive seafloor spreading and the development of oceanic ridges.

- Geological Significance: Paleo-Tethys had a significant impact on the geological and paleoclimatic history of Earth during the late Paleozoic and Mesozoic eras. It influenced the distribution of landmasses, ocean currents, and climate patterns. The closure of Paleo-Tethys through subduction and collision processes played a crucial role in the formation of mountain ranges and the assembly of supercontinents such as Pangaea.

The Cimmerian orogeny is indeed linked to the closure of the Paleo-Tethys Ocean, which occurred during the Late Paleozoic and Early Mesozoic eras. The collision and subsequent suturing of terranes along the northern margin of Gondwana with the southern margin of Laurasia led to the formation of the Cimmerian orogen. This collision resulted in the uplift of mountain belts and the formation of extensive thrust faulting, folding, and metamorphism. In summary, Proto-Tethys represents the early stages of the Tethys Ocean system, while Paleo-Tethys represents a more advanced stage characterized by wider oceanic expanses and significant geological activity. Both stages played essential roles in shaping Earth's geology and paleoclimate during different periods of geological history.

So, to clarify, while the Iranian Plateau does contain remnants of both the Proto-Tethys and Paleo-

Tethys oceans, the Cimmerian orogeny is primarily associated with the closure of the Paleo-Tethys Ocean and the subsequent tectonic events during the late Paleozoic and early Mesozoic eras.

## Critique et Revoir à la Téthys

Le Proto-Téthys est un océan ancien qui a existé du dernier période Édiacarien jusqu'au Carbonifère, contribuant de manière significative à l'évolution géologique de la Terre pendant cette période. Il a joué un rôle crucial dans la dispersion des continents et la formation de nouvelle croûte océanique, influençant la configuration des terres émergées et des bassins océaniques au début de l'ère Paléozoïque. Le Proto-Téthys et le Paléo-Téthys sont deux étapes distinctes dans l'évolution du système de l'océan Téthys. Le Proto-Téthys, qui s'est formé lors de la séparation des supercontinents Rodinia et a continué à se développer pendant la formation de Pangée, était étroit et allongé. Sa fermeture et l'amalgamation des fragments continentaux le long de ses marges ont joué un rôle majeur dans l'évolution tectonique de la région. Le Paléo-Téthys, quant à lui, était plus large et s'est formé avec la poursuite de la fragmentation de Pangée, caractérisé par une extension significative du plancher océanique.

La fermeture du Paléo-Téthys, à travers des processus de subduction et de collision, a eu un impact majeur sur l'histoire géologique et paléoclimatique de la Terre, influençant la distribution des terres émergées, les courants océaniques et les schémas climatiques. La collision et la suture des terraines le long de la marge nord de Gondwana avec la marge sud de Laurasia ont conduit à la formation de l'orogénèse

Cimmérienne, caractérisée par le soulèvement de chaînes de montagnes et la formation de failles de chevauchement, de plissements et de métamorphisme étendus.

Le plateau iranien est connu pour sa géologie complexe, comprenant des vestiges de l'océan Proto-Téthys et des zones de suture résultant de la fermeture d'anciens bassins océaniques. Des zones notables comme le suture Zagros, la zone Sanandaj-Sirjan, les montagnes Alborz et des régions centrales comme Yazd et Kerman présentent des roches ophiolitiques et des complexes métamorphiques associés aux vestiges de l'océan Proto-Téthys. La complexité géologique du plateau iranien reflète son histoire tectonique riche, incluant la fermeture de l'océan Proto-Téthys et les événements tectoniques subséquents liés à la collision des plaques.

En résumé, les océans Proto-Téthys et Paléo-Téthys ont joué des rôles essentiels dans la géologie et le climat de la Terre durant différentes périodes de son histoire. Le plateau iranien offre un aperçu de cette évolution géologique avec ses vestiges océaniques et ses zones de suture, tandis que l'orogénèse Cimmérienne est principalement liée à la fermeture du Paléo-Téthys et aux événements tectoniques qui ont suivi.

Le Proto-Téthys Océan a joué un rôle crucial dans l'évolution géologique de la Terre en contribuant à la dispersion des continents et à la formation de nouvelle croûte océanique. Son existence, du dernier période Édiacarien jusqu'au Carbonifère, a influencé la configuration des terres émergées et des bassins océaniques au début de l'ère Paléozoïque. L'évolution du Proto-Téthys a également participé à la configuration des landes et des bassins océaniques pendant les premiers stades de l'ère Paléozoïque. Son ouverture initiale, résultant de la séparation des landes, a marqué le début du système de l'océan Téthys, qui a continué à se développer avec la formation de Pangée. La fermeture du Proto-Téthys Océan et l'amalgamation des fragments continentaux le long de ses marges ont joué un rôle majeur dans l'évolution tectonique de la région.

Le Proto-Téthys et le Paléo-Téthys sont deux étapes distinctes dans l'évolution du système de l'océan Téthys, se différenciant par leur âge et leurs caractéristiques :

**1. Proto-Téthys:**

- Période : Du dernier Édiacarien au Carbonifère (environ 570 à 300 millions d'années).
- Emplacement : Initialement situé entre les supercontinents de Laurentia et Gondwana.
- Caractéristiques : Le Proto-Téthys était un précurseur précoce du système de l'océan Téthys. Il s'est formé pendant la rupture du supercontinent Rodinia et a continué à se développer pendant que Pangée commençait à se former. Le Proto-Téthys était

relativement étroit et allongé, avec son ouverture initiale résultant de la séparation des masses terrestres.

**2. Paléo-Téthys:**

- Période : Du Paléozoïque tardif au Mésozoïque (environ 300 à 140 millions d'années).
- Emplacement : Formé pendant que Pangée continuait à se briser, situé entre les continents nouvellement formés de Laurasia et Gondwana.
- Caractéristiques : Le Paléo-Téthys était plus large et plus expansif par rapport au Proto-Téthys. Il a résulté de la rupture continue de Pangée et de l'ouverture de bassins océaniques entre Laurasia et Gondwana. Le Paléo-Téthys était caractérisé par une extension significative du plancher océanique et le développement de dorsales océaniques.

En résumé, le Proto-Téthys représente les premiers stades du système de l'océan Téthys, tandis que le Paléo-Téthys représente une étape plus avancée caractérisée par de plus vastes étendues océaniques et une activité géologique significative. Les deux étapes ont joué des rôles essentiels dans le façonnage de la géologie et du paléoclimat de la Terre pendant différentes périodes de l'histoire géologique. Le plateau iranien contient plusieurs zones où l'on peut observer des traces de l'océan Proto-Téthys, notamment :

1. Zone de suture Zagros :

- Les montagnes Zagros au sud-ouest de l'Iran constituent une importante zone de suture formée par la fermeture de l'océan Néo-Téthys pendant l'ère Cénozoïque.
- Bien que les montagnes Zagros représentent principalement la fermeture du Néo-Téthys, elles contiennent également des vestiges et des caractéristiques tectoniques liés au Proto-Téthys antérieur.

2. Zone Sanandaj-Sirjan :

- La zone Sanandaj-Sirjan est une zone tectonique significative dans l'ouest de l'Iran qui représente la suture entre le plateau iranien et la plaque arabe.
- Cette zone contient un assemblage complexe de roches, y compris des ophiolites, des schistes bleus et d'autres vestiges océaniques, qui sont interprétés comme des vestiges de l'océan Proto-Téthys.

3. Montagnes Alborz :

- Les montagnes Alborz au nord de l'Iran sont un autre endroit où l'on peut trouver des vestiges du Proto-Téthys.
- La région d'Alborz contient des complexes ophiolitiques et d'autres caractéristiques géologiques associées à la fermeture d'anciens bassins océaniques pendant les ères Paléozoïque et Mésozoïque.

4. Plateau iranien central :

- Dans le centre de l'Iran, en particulier dans des régions comme Yazd et Kerman, il y a des affleurements de roches ophiolitiques et de complexes métamorphiques associés qui sont considérés comme des vestiges de l'océan Proto-Téthys.

- Ces zones fournissent des aperçus de l'histoire tectonique et de l'évolution du plateau iranien pendant les ères Paléozoïque et Mésozoïque. Ces zones offrent des preuves géologiques de l'existence et de l'évolution de l'océan Proto-Téthys, ainsi que des processus tectoniques qui ont façonné le plateau iranien au cours de l'histoire de la Terre. L'orogenèse cimmérienne est liée à la fermeture de l'océan Paléo-Téthys, qui s'est produite pendant le Paléozoïque tardif et le Mésozoïque précoce. La collision et la suture subséquente des terraines le long de la marge nord de Gondwana avec la marge sud de Laurasia ont conduit à la formation de l'orogénèse cimmérienne. Cette collision a entraîné le soulèvement de chaînes de montagnes et la formation de failles de chevauchement, de plissements et de métamorphisme étendus. L'orogenèse cimmérienne est donc principalement associée à la fermeture de l'océan Paléo-Téthys et aux événements tectoniques qui ont suivi, plutôt qu'à l'océan Proto-Téthys.

## Introduction

The Proto-Tethys Ocean played a crucial role in Earth's geological evolution from the late Ediacaran to the Carboniferous period, preceding the formation of the modern Tethys Ocean. This ancient ocean basin shaped continents, ocean circulation patterns, and global climate dynamics during the Paleozoic era.

Research in East Asia has detailed the evolution of the Proto-Tethys Ocean, from the breakup of the Rodinia supercontinent to the incorporation of micro-continents and eventual closure, forming continental Gondwana around 431-420 Ma. This ~200 Myr process, driven by south-vergent subduction and back-arc extension, was marked by significant events such as the Cadomian volcanic arc formation above the subduction zone facing Gondwana's northern margin.

However, the amalgamation of Gondwanian terranes in Iran remains poorly understood. Despite early research dividing the Iranian plateau into major continental blocks, the geodynamics of Central Iran, spanning from the Northern Alborz to the Arabian plate, remain unclear. Although Precambrian to early Paleozoic rocks are exposed in the region, the evolution of the Proto-Tethys Ocean and related geodynamic events in Iran are not well documented. By compiling published data on the oldest rock units and inherited structures, this study presents a novel synthesis of the Iranian geological evolution, with significant implications for metallogeny.

The Iranian plateau's geological evolution is closely tied to the dynamics of the Proto-Tethys Ocean, which significantly shaped the region's tectonic landscape. By integrating data from Iran, Turkey, and China, researchers can gain a deeper understanding of the Proto-Tethys' role in regional tectonics, revealing patterns in oceanic subduction, magmatism, and metamorphism that are key to unraveling the complex geodynamic history shared among these regions. This comprehensive understanding not only sheds light on the tectonic evolution narrative but also informs future research on resource exploration and environmental assessment across these connected landscapes.The Iranian plateau's geological evolution is closely tied to the dynamics of the Proto-Tethys Ocean, which significantly shaped the region's tectonic landscape. By integrating data from Iran, Turkey, and China, researchers can gain a deeper understanding of the Proto-Tethys' role in regional tectonics, revealing patterns in oceanic subduction, magmatism, and metamorphism that are key to unraveling the complex geodynamic history shared among these regions. This comprehensive understanding not only sheds light on the tectonic evolution narrative but also informs future research on resource exploration and environmental assessment across these connected landscapes. Furthermore, the Proto-Tethys Ocean's closure and subsequent continental collision have led to the formation of numerous mountain ranges, including the Zagros and Alborz mountains in Iran, which are characterized by unique structural and petrological features. A multidisciplinary approach, combining geophysical, geochemical, and geological data, is essential for reconstructing the paleogeographic and paleotectonic settings of the Proto-Tethys Ocean and its surrounding regions. By elucidating the spatiotemporal relationships between tectonic events, magmatic activity, and metamorphic processes, scientists can develop a more nuanced understanding of the region's geological history, ultimately contributing to a better assessment of natural resources, such as hydrocarbons, minerals, and groundwater, and mitigating geological hazards like earthquakes and landslides. Additionally, the study of the Proto-Tethys Ocean's evolution has significant implications for our understanding of global geodynamic processes, including the break-up and assembly of supercontinents, the formation of oceanic and continental crust, and the resulting impact on Earth's climate and ecosystems.The Iranian plateau's geological evolution is closely tied to the dynamics of the Proto-Tethys Ocean, which significantly shaped the region's tectonic landscape. By integrating data from

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## Geology and tectonic setting

Geology and tectonic setting of the region east of the Mediterranean are characterized by rock units affected by the Pan-African orogeny, found in Central Iran and Turkey. These units are unconformably overlain by Paleozoic units and were later metamorphosed. The oldest rock units include the Kahar Formation in Alborz and Azarbaijan, the Boneshorow and Tashk Formations in the Yazd area, the Morad Series in the Kerman region, and the Hormoz series exposed in salt diapirs along the Zagros orogen.

The presence of these rock units provides valuable insights into the geological history of the region, which has been shaped by a complex series of tectonic events.

Although the base of these reworked basin formations is not exposed, absolute age dating has provided valuable information on their geology. The Kahar Formation, a siliciclastic formation with Late Neoproterozoic horizons, indicates an active subduction setting around 560 Ma. This formation can be correlated with the Ara Formation in Oman, the Hormoz series, and the Tashk Formation, which comprises metamorphosed sedimentary, volcanic, and volcano-sedimentary units. The Tashk Formation, dated at 627 ± 19 Ma, likely formed near the slope break of the continental shelf. In contrast, the adjacent Boneh shurow Formation features higher-grade gneiss, micaschist, and garnet amphibolite dated at 547.6 ± 2 Ma. The age of these formations provides a framework for understanding the geological history of the region, with the Kahar Formation indicating an active subduction setting and the Boneh shurow Formation indicating a deeper level of exposure.

Despite recent advances in geochronology, the geodynamic history of the Iranian plateau remains a topic of debate. The complexities of the Iranian plateau's geodynamic history are further exacerbated by the presence of multiple tectonic phases, including the Cadomian and Pan-African orogenies, which have resulted in the formation of a heterogeneous crustal architecture. The Kahar Formation, for instance, exhibits a mix of siliciclastic and carbonate units, suggesting a transition from a shallow marine to a deeper marine environment. In contrast, the Hormoz series, which is characterized by the presence of salt diapirs, is thought to have formed in a rift setting, possibly related to the break-up of the supercontinent Gondwana. The Tashk Formation, with its unique assemblage of metamorphosed sedimentary, volcanic, and volcano-sedimentary units, provides valuable insights into the tectonic evolution of the region, particularly with regards to the subduction processes that occurred during the Neoproterozoic era.

Furthermore, the Boneh shurow Formation, with its high-grade metamorphic rocks, indicates a deeper level of exposure, potentially related to the collisional tectonics that characterized the region during the Paleozoic era. The absolute age dating of these formations has provided a framework for understanding the geological history of the region, with ages ranging from 627 ± 19 Ma for the Tashk Formation to 547.6 ± 2 Ma for the Boneh shurow Formation, highlighting the complex and protracted nature of the tectonic processes that have shaped the Iranian plateau. The correlation between these formations and other rock units in the region, such as the Ara

Formation in Oman, provides further evidence for the complex geological history of the region.

The geological history of the region is also characterized by the presence of multiple tectonic phases, including the Cadomian and Pan-African orogenies, which have resulted in the formation of a heterogeneous crustal architecture. The Kahar Formation, for example, exhibits a mix of siliciclastic and carbonate units, suggesting a transition from a shallow marine to a deeper marine environment. In contrast, the Hormoz series, which is characterized by the presence of salt diapirs, is thought to have formed in a rift setting, possibly related to the break-up of the supercontinent Gondwana. The Tashk Formation, with its unique assemblage of metamorphosed sedimentary, volcanic, and volcano-sedimentary units, provides valuable insights into the tectonic evolution of the region, particularly with regards to the subduction processes that occurred during the Neoproterozoic era.

Despite these advances, however, much remains to be discovered about the geodynamic history of the region, and ongoing research is focused on integrating geological, geochronological, and geochemical data to develop a more comprehensive understanding of the tectonic evolution of the Iranian plateau. The absolute age dating of the formations in the region has provided a framework for understanding the geological history, but further research is needed to fully understand the complexities of the region's geodynamic history. The correlation between the formations in the region and other rock units, such as the Ara Formation in Oman, provides further evidence for the complex geological history of the region, and highlights the need for further research into the tectonic evolution of the Iranian plateau. The geological history of the region is complex and protracted, and further research is needed to fully understand the processes that have shaped the Iranian plateau over millions of years.

The geological history of the Iranian plateau is a complex and fascinating topic, with many different rock units and formations providing valuable insights into the region's tectonic evolution. The Kahar Formation, the Tashk Formation, and the Boneh shurow Formation are just a few examples of the many formations that make up the geological history of the region. Each of these formations provides valuable information about the geological history of the region, and together they provide a comprehensive understanding of the tectonic evolution of the Iranian plateau. The absolute age dating of these formations has provided a framework for understanding the geological history of the region, and further research is needed to fully understand the complexities of the region's geodynamic history.

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The geodynamic history of the Iranian plateau remains a topic of debate, with many different theories and models attempting to explain the complex tectonic evolution of the region. The presence of multiple tectonic phases, including the Cadomian and Pan-African orogenies, has resulted in the formation of a heterogeneous crustal architecture, with many different rock units and formations providing valuable insights into the region's tectonic evolution. The absolute age dating of these formations has provided a framework for understanding the geological history of the region, but further research is needed to fully understand the complexities of the region's geodynamic history. The correlation between these formations and other rock units in the region, such as the Ara Formation in Oman, provides further evidence for the complex geological history of the region.

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## Regional observation and Synthesis

### Proto-Tethys in Iran

The Iranian plateau lacks exposed crystalline basement, with the oldest rock units being the Kahar Formation in Alborz-Azarbaijan, the Boneh shurow-

Tashk Formations in Central Iran, and the Hormoz series in the Zagros. Despite their similar magmatic ages, the scattered distribution of these units makes it challenging to determine their origin. However, detrital zircon grains in these formations provide insight into the nature and age of the underlying crystalline basement.

The magmatic evolution of the Proto-Tethys in Iran has been explored by several authors, who suggest that old plutons with Late Paleoproterozoic-Early Paleozoic ages are associated with the Proto-Tethys or Cadomian event. Meanwhile, Paleozoic metamorphic rocks in the Alborz range and Central Iran are thought to have originated from the Paleo-Tethys.

A significant pulse of granitization occurred across the Iranian plateau around 540-550 Ma, marked by the generation of granitoids from the Alborz to the southern Sanandaj- Sirjan zone. In western Alborz, medium to high-grade metamorphic rocks of the Gasht Complex and the Precambrian Shanderman series are overlain by Lower Paleozoic metamorphic rocks and later by Devonian calcareous units. This sequence extends into eastern Alborz, where the Gorgan schists coexist with oceanic material and are unconformably overlain by Devonian limestone.

The presence of high-grade metamorphic rocks with an age of approximately 530 million years near the

North Alborz Fault suggests that these rocks may have been part of the ancient continental margin or oceanic crust associated with the closure of the Proto-Tethys Ocean. It is likely that these rocks underwent intense tectonic and metamorphic processes during the closure of the Proto-Tethys Ocean and subsequent collision and accretion events along the northern margin of Gondwana. The Gasht Complex's high-grade metamorphic rocks, with ages older than 530 million years, indicate a complex tectonic history involving the closure of ancient oceanic basins and subsequent tectonic events associated with plate collision and mountain building.The tectonic evolution of the Iranian plateau is further complicated by the presence of ophiolitic remnants and accretionary complexes, which provide evidence of multiple phases of oceanic crust formation and destruction. The presence of these ophiolites, such as the Sabzevar ophiolite in northeastern Iran, suggests that the Proto-Tethys Ocean was characterized by a complex system of oceanic ridges, transform faults, and subduction zones. The accretionary complexes, including the Zagros Accretionary Complex, contain a diverse range of rocks, including metamorphic rocks, volcanic arcs, and oceanic crust, which were formed during the closure of the Proto-Tethys Ocean and the subsequent collision between the Iranian plateau and the Arabian plate.

The metamorphic rocks in the Alborz range and Central Iran exhibit a range of metamorphic grades, from low-grade phyllites to high-grade eclogites, which indicate a complex pressure-temperature history. The presence of high-pressure metamorphic rocks, such as eclogites and blueschists, suggests that these rocks were subducted to great depths during the closure of the Proto-Tethys Ocean. The subsequent exhumation of these rocks is thought to have occurred during the collision and accretion events that formed the Iranian plateau.

The geochronological data from the Iranian plateau indicate that the tectonic evolution of the region was characterized by multiple phases of magmatic and metamorphic activity. The oldest rocks in the region, including the Kahar Formation and the Hormoz series, have ages ranging from 700 to 900 Ma, which suggests that the Iranian plateau was part of a larger continental margin or oceanic basin during the Neoproterozoic era. The subsequent phases of magmatic and metamorphic activity, including the generation of granitoids and the formation of high-grade metamorphic rocks, are thought to have occurred during the Paleozoic and Mesozoic eras, and are related to the closure of the Proto-Tethys Ocean and the subsequent collision and accretion events. The tectonic history of the Iranian plateau is also reflected in the geochemical signature of the rocks in the region. The granitoids and metamorphic rocks in the Alborz range and Central Iran exhibit a range of geochemical characteristics, including depleted mantle-like signatures and enriched crustal signatures, which suggest that the rocks were formed from a variety of sources, including mantle and crustal rocks. The presence of rocks with enriched crustal signatures, such as the granitoids in the Sanandaj-Sirjan zone, suggests that the Iranian plateau was affected by crustal thickening and melting during the collision and accretion events.

Overall, the tectonic evolution of the Iranian plateau is a complex and multifaceted process that involved the closure of the Proto-Tethys Ocean, the collision and accretion of multiple continental fragments, and the formation of a range of metamorphic and magmatic rocks. The geochronological, geochemical, and petrological data from the region provide a detailed record of the tectonic history of the Iranian plateau, and highlight the importance of this region in understanding the geological evolution of the Middle East and the formation of the Eurasian plate.

The geology of Iran is characterized by the presence of Upper Devonian deposits overlying older rock units through unconformity or nonconformity, a feature observed in various regions, including Western

Alborz, Eastern Alborz, Central Iran, and the southern Sanandaj-Sirjan zone. This phenomenon is also seen in East Asia, where Devonian rocks unconformably overlie Early Paleozoic strata. The temperature range of metamorphic rocks beneath the Devonian in the Sanandaj-Sirjan zone supports this observation, providing further evidence of the geological processes that have shaped the region. We propose that this feature marks the final closure of the Proto-Tethys Ocean during the Lower Devonian, around 431-420 Ma, a significant event in the geological history of Iran.

The break-up of the Rhodinia supercontinent during the Neoproterozoic led to the opening of the Proto-Tethys Ocean, which subsequently subducted southwards beneath Iran and China, resulting in a complex series of geological events. The suture of the Proto-Tethys is thought to coincide with the present-day North Alborz fault, based on the location and type of metamorphic assemblages and ophiolite rocks found in the region. The structural features affecting the Precambrian and Early Paleozoic highlands in central Alborz, as well as the ophiolitic/metamorphic assemblages and high-pressure metamorphic complexes in northern Iran, are considered part of the Proto-Tethys evolution, highlighting the significance of this event in shaping the geology of the region. The closure of the Proto-Tethys Ocean during the Lower Devonian had a profound impact on the geology of Iran, resulting in the formation of a series of thrust faults and fold belts that shaped the country's mountain ranges, including the Alborz and Zagros Mountains.

The Sanandaj-Sirjan zone, in particular, exhibits a complex geological history, with evidence of multiple phases of deformation and metamorphism, reflecting the intense tectonic activity that occurred in the region. The presence of high-pressure metamorphic rocks, such as eclogites and blueschists, in this region suggests that the crust was subjected to intense pressure and heat during the subduction process, resulting in the formation of unique geological structures. Furthermore, the occurrence of ophiolitic rocks and metamorphic assemblages along the North Alborz fault supports the idea that this structure marks the suture zone of the Proto-Tethys Ocean, providing valuable insights into the geological evolution of the region.

The geological evolution of Iran during the Paleozoic and Mesozoic eras was also influenced by the break-up of the Gondwana supercontinent and the subsequent formation of the Neotethys Ocean, a significant event that shaped the geology of the region. The rifting and sea-floor spreading that accompanied the opening of the Neotethys led to the creation of new oceanic crust and the formation of passive margins along the southern edge of Iran, resulting in the deposition of unique sedimentary sequences. The sedimentary sequences deposited during this period, including the famous Permian-Triassic reefs of the Zagros Mountains, provide valuable insights into the paleoenvironmental and paleogeographic conditions that prevailed in the region, highlighting the complex geological history of Iran.

In addition to the tectonic processes that shaped the geology of Iran, the country's unique position at the intersection of several major fault lines has resulted in a complex pattern of seismic activity, posing significant risks to the region's population and infrastructure. The North Alborz fault, in particular, is considered a major seismic hazard, with the potential to generate large earthquakes that could have significant impacts on the region. Understanding the geological history and tectonic evolution of Iran is therefore crucial for mitigating the risks associated with seismic activity and for exploring the country's significant mineral and energy resources, which are essential for the country's economic development. The geological history of Iran is complex and multifaceted, reflecting the interaction of various tectonic processes that have shaped the region over millions of years, and continued research and study are necessary to fully understand the geological evolution of the region.

## Proto-Tethys in Turkey

In Turkey, the Eurasian and Arabian plates' tectonic interactions have formed notable geological structures, such as the Tauride and Sakarya complexes, which bear a resemblance to Iranian formations in terms of their composition and characteristics. Ophiolitic remnants and high-pressure metamorphic rocks indicate past oceanic subduction zones, similar to those found along Iran's North Alborz fault, where the evidence of subduction is well-documented. The terranes amalgamated during the Late Paleozoic to Early Mesozoic, marked by intense magmatic activity dated to 550-490 Ma, coinciding with granitization events in the Iranian plateau, as reported by Ustaömer and Kuscu in their research published in 2021. This significant geological event had a profound impact on the formation of the region's crustal architecture.

The convergence of these terranes led to the formation of a complex orogenic belt, characterized by multiple phases of deformation, metamorphism, and magmatism, resulting in a unique and intricate geological landscape. The resulting geological architecture is marked by a mosaic of crustal fragments, including the Istanbul and Sakarya zones, which exhibit distinct petrological and geochemical signatures, reflecting their diverse origins and evolutionary histories. The Late Cretaceous to Paleocene period saw significant tectonic reorganization, with the initiation of north-south shortening and the development of major fault systems, such as the North Anatolian Fault Zone, which played a crucial role in shaping the region's geological framework.

This phase of deformation was accompanied by widespread volcanic activity, with the eruption of calc-alkaline to alkaline magmatic rocks, similar to those found in the Urumieh-Dokhtar magmatic arc in Iran, where volcanic activity has been documented to be intense and widespread. The tectonic evolution of Turkey and Iran shares many similarities, suggesting a shared geological history, with both regions experiencing multiple phases of oceanic subduction, continental collision, and post-collisional extension, as highlighted by Ustaömer and Kuscu in their research published in 2021 and Zanchi et al. in their study published in 2009. The similarities between the two regions are striking, with both exhibiting evidence of complex tectonic processes that have shaped their geological landscapes over millions of years. The geological history of Turkey and Iran is characterized by a series of complex and interconnected events, including the formation of oceanic subduction zones, the collision of continental plates, and the resulting deformation and metamorphism of the Earth's crust.

## Proto-Tethys in China

China's geological evolution offers valuable comparative insights, particularly in the North China Craton and Qiongdongnan Basin, where tectonic signatures of ancient oceanic environments and subduction processes mirror those found in Iran, providing a unique opportunity for in-depth analysis and comparison. The opening and closing of the Proto-Tethys, which formed back-arc basins, are well-documented in the Yangtze Block's interaction with surrounding lithospheric elements, and have been extensively studied in terms of their geological implications. Geological studies indicate that the Proto-Tethys facilitated the subduction of oceanic crust beneath the Eurasian continental margin, influencing metamorphic events around 500-420 Ma, a period of significant geological activity in the region. The presence of Devonian sedimentary sequences alongside older rock units in both Eastern Iran and Central China highlights their shared geological heritage, shaped by Proto-Tethys oceanic processes, and underscores the importance of considering the regional geological context in understanding the evolution of these areas.

Furthermore, the similarities in geological evolution between Eastern Iran and Central China are further underscored by the presence of ophiolitic complexes and blueschist facies, which are indicative of high-pressure metamorphism associated with subduction zones, and have been identified as key features of the regional geology. The Songpan-Ganzi terrane in the North China Craton, for instance, exhibits a complex tectonic history characterized by multiple episodes of oceanic subduction and continental collision, mirroring the tectonic evolution of the Sanandaj-Sirjan Zone in Iran, and providing valuable insights into the geological processes that have shaped the region. The accretionary complexes and melanges found in both regions also attest to the common geological processes that have shaped their respective crustal architectures, and highlight the significance of comparative studies in reconstructing the complex tectonic history of the Eurasian continent. Additionally, the geochemical signatures of granitic rocks in the Qiongdongnan Basin and the Urumieh-Dokhtar Magmatic Arc in Iran display striking similarities, suggesting a shared mantle source and tectonic setting, and underscoring the importance of geochemical analysis in understanding the geological evolution of the region.

These converging lines of evidence collectively underscore the significance of the Proto-Tethys in shaping the geological heritage of both Eastern Iran and Central China, and highlight the importance of comparative studies in reconstructing the complex tectonic history of the Eurasian continent, a region of significant geological complexity and interest. The parallels in geological evolution between Eastern Iran and Central China are further reinforced by the presence of analogous magmatic arcs, such as the Urumieh-Dokhtar Magmatic Arc in Iran and the Qinling-Dabie-Sulu orogenic belt in China, which exhibit similar geochemical and petrological characteristics, and have been the subject of extensive geological research. These magmatic arcs are thought to have formed as a result of subduction of the Proto-Tethys oceanic crust beneath the Eurasian continental margin, leading to the generation of arc-related magmas and the formation of granitic rocks with distinct geochemical signatures, a process that has been well-documented in the geological literature.

The similarities in the geochemical composition of these granitic rocks, including their major and trace element characteristics, suggest a shared tectonic setting and mantle source, underscoring the genetic link between the two regions, and highlighting the importance of geochemical analysis in understanding the geological evolution of the region. Moreover, the presence of coeval metamorphic events, such as the high-pressure metamorphism recorded in the blueschist facies of the Sanandaj-Sirjan Zone and the Songpan-Ganzi terrane, provides further evidence of the shared tectonic history of Eastern Iran and Central China, and underscores the significance of considering the regional geological context in understanding the evolution of these areas. The temporal and spatial correlation of these metamorphic events, which occurred around 500-420 Ma, highlights the significance of the Proto-Tethys in shaping the geological evolution of the Eurasian continent, a region of significant geological complexity and interest. The comparative study of the geological evolution of Eastern Iran and Central China thus offers a unique opportunity to reconstruct the complex tectonic history of the region, and to gain insights into the processes that have shaped the Earth's crust over millions of years, a topic of ongoing research and debate in the geological community.

By integrating geological, geochemical, and geophysical data from both regions, researchers can develop a more comprehensive understanding of the tectonic processes that have controlled the evolution of the Eurasian continent, and shed light on the complex interactions between the Earth's lithosphere, mantle, and crust, a topic of significant interest and importance in the field of geology. The similarities in geological evolution between Eastern Iran and Central China are a testament to the shared geological heritage of the region, and highlight the importance of considering the regional geological context in understanding the evolution of these areas. The presence of analogous geological features, such as ophiolitic complexes and blueschist facies, underscores the significance of comparative studies in reconstructing the complex tectonic history of the Eurasian continent, and provides valuable insights into the geological processes that have shaped the region. The geochemical signatures of granitic rocks in the Qiongdongnan Basin and the Urumieh-Dokhtar Magmatic Arc in Iran display striking similarities, suggesting a shared mantle source and tectonic setting, and highlighting the importance of geochemical analysis in understanding the geological evolution of the region. Overall, the comparative study of the geological evolution of Eastern Iran and Central China offers a unique opportunity to gain insights into the processes that have shaped the Earth's crust over millions of years, and to develop a more comprehensive understanding of the tectonic processes that have controlled the evolution of the Eurasian continent.

## Synthesize and Comparation

The exact size of the Proto-Tethys Ocean is unknown, but its southward subduction likely led to the formation of two back-arc basins in the upper plate during the upper Proterozoic. This process is supported by the presence of high-pressure rocks along the northern Alborz suture and the oceanic affinity of the Cadomian magmatic activity in the upper plate, which was part of Northern Gondwana at the time. The development of a back-arc setting in Central Iran is evidenced by the Boneh Shurow Formation and Takab

Complex, with the Boneh Shurow garnet amphibolites suggesting intra-oceanic subduction. The lithostratigraphic and metamorphic similarities between these two formations indicate a shared back-arc setting, although oceanic remnants are better preserved in Takab.

In southern Iran, the Hormoz series salt diapirs expose sedimentary, magmatic-metamorphic rocks, and rare oceanic fragments, associated with basalts and gabbros of tholeiitic affinity, as well as serpentinites. This suggests formation in an oceanic domain, likely during seafloor spreading in a back-arc setting. The km-thick evaporites of the Hormoz basin are similar to those found in the Red Sea and may have formed through serpentinization and hydrothermal processes. This evaporitic marine basin, which extends to Oman, Pakistan, and India, marks the existence of a large, single basin overlying Gondwana.

The diabases and gabbros of the Hormoz series have E-MORB and N-MORB affinities, indicating the beginning of rifting and later evolution of the basin. Iron and copper deposits formed in basinal conditions are observed in the Hormoz diapirs, strengthening the existence of an oceanic domain. The formation of iron may be ascribed to E-MORB magmatism or asthenospheric upwelling, while copper genesis likely corresponds to massive sulfide deposits following breakup and oceanic crust formation.

The mafic magmatic rocks are associated with rhyolites, which could relate to rifting processes or result from subduction along an active margin. However, the similar ages and spatial association of rhyolites and mafic rocks suggest that decompression during early rifting led to the genesis of both E-MORB and acidic magmas.The coexistence of mafic and felsic magmatic rocks in the Hormoz series, along with the presence of iron and copper deposits, implies a complex geological history involving both rifting and subduction processes. The E-MORB and N-MORB affinities of the diabases and gabbros suggest that the Hormoz basin underwent a transition from a back-arc setting to a more mature oceanic basin, possibly as a result of the continued southward subduction of the Proto-Tethys Ocean. The serpentinization and hydrothermal processes that formed the km-thick evaporites in the Hormoz basin may have also played a role in the formation of the iron and copper deposits, highlighting the importance of fluid-rock interactions in the evolution of the basin.

The spatial and temporal relationships between the Hormoz series and the Cadomian magmatic activity in the upper plate of Northern Gondwana suggest that the two are genetically linked, with the Hormoz basin representing a distal expression of the back-arc setting that developed in response to the subduction of the Proto-Tethys Ocean. The presence of high-pressure rocks along the northern Alborz suture and the oceanic affinity of the Cadomian magmatic activity support this interpretation, implying that the Hormoz basin was part of a larger, complex system that involved the interaction of multiple tectonic plates and geological processes.

The extension of the Hormoz basin to Oman, Pakistan, and India, as evidenced by the presence of similar evaporitic marine basins in these regions, highlights the regional significance of the Proto-Tethys Ocean and its role in shaping the geological evolution of the area. The formation of a large, single basin overlying Gondwana during the upper Proterozoic suggests that the supercontinent was undergoing significant tectonic reorganization at this time, possibly in response to changes in the global mantle circulation patterns or the break-up of a previous supercontinent.

The presence of rhyolites in the Hormoz series, which could relate to rifting processes or result from subduction along an active margin, adds another layer of complexity to the geological history of the region. The similar ages and spatial association of rhyolites and mafic rocks suggest that decompression during early rifting led to the genesis of both E-MORB and acidic magmas, implying that the Hormoz basin underwent a period of extensional tectonics that was accompanied by significant magmatic activity. The interplay between rifting, subduction, and magmatism in the Hormoz basin provides a unique window into the geological processes that shaped the evolution of the Proto-Tethys Ocean and the surrounding regions during the upper Proterozoic.

## Discussion and Conclusion

This study proposes that the suture of the large-scale Proto-Tethys Ocean is located along the present-day North Alborz fault, which preserves a range of medium to high-pressure metamorphic rocks, including those in the Gasht complex, Precambrian Shanderman series, and Gorgan schists. Magmatic ages clustering around 580-520 Ma suggests a need to restore the region's paleogeodynamic configuration. Our research suggests the existence of three adjacent oceanic bodies with distinct subduction dynamics: the Proto-Tethys Ocean in northern Iran and two back-arcs in Central Iran and the Zagros domain. Subduction likely began in the upper Precambrian in the Alborz and Central Iran, coinciding with remnants of oceanic crust in western Alborz, Anarak, the southern Sanandaj-Sirjan zone, and Takab regions.The reconstructed paleogeodynamic framework implies that the closure of the Proto-Tethys Ocean led to the formation of a collisional orogen, resulting in the exhumation of the metamorphic rocks along the North Alborz fault. Geochemical signatures of the magmatic rocks in the region indicate a subduction-related origin, with the presence of continental crust-derived melts and mantle-derived magmas. The tectonic evolution of the region is further complicated by the presence of ophiolitic remnants, which suggest multiple episodes of oceanic crust formation and destruction. The Gorgan schists, in particular, exhibit a unique metamorphic signature, with peak pressures estimated to be around 1.5-2.0 GPa, indicating a deep subduction of the continental crust. Our findings suggest that the Proto-Tethys Ocean played a crucial role in shaping the geological history of northern Iran, with the North Alborz fault serving as a major suture zone that preserves a record of the ocean's closure and the resulting orogenic activity. Furthermore, the presence of back-arc basins in Central Iran and the Zagros domain implies a complex interplay between subduction and continental rifting, which ultimately led to the formation of the modern-day Iranian plateau.

A comprehensive comparative analysis of geological data from Turkey and China significantly enhances the context of our findings. Turkey's tectonic history, characterized by intricate interactions between the Eurasian and Arabian plates, closely parallels that of Iran. This is evident through the presence of notable ophiolitic remnants and high-pressure metamorphic complexes in both regions. Such geological formations underscore the extensive influence of ancient oceanic processes and highlight the interconnected nature of these tectonic settings.

In China, particularly within the Yangtze Block, the documentation of subduction processes related to the Proto-Tethys Ocean reveals geological evolutions that run parallel to our observations in Iran. The evidence of significant metamorphic events and sedimentary sequences in China aligns with the tectonic timelines identified on the Iranian plateau. These interactions between the geological environments of Iran, Turkey, and China underscore a shared geodynamic history shaped by the Proto-Tethys Ocean. This history is characterized by the cyclical opening and closing of ancient oceans, subduction events, and associated magmatic activities.

The implications of this study extend well beyond the geological understanding of Iran alone. By exploring the interconnections between these regions, we uncover a broader narrative of continental assembly and rifting, heavily influenced by ancient oceanic dynamics. Future research will greatly benefit from further investigations into these relationships, as they hold the key to unraveling the complex geological evolution of the region. Understanding the shared tectonic heritage of Iran, Turkey, and China will not only deepen our comprehension of Earth's history but also guide future mineral exploration and environmental studies across these historically interconnected landscapes.

Moreover, this study emphasizes the importance of considering regional tectonic contexts to fully grasp the geological evolution of a specific area. This approach can be applied to other regions with similar tectonic settings, providing valuable insights into their geological histories. The comparative analysis of these regions also highlights the value of interdisciplinary research, which combines geological, geophysical, and geochemical data to reconstruct Earth's history and better understand the complex processes that have shaped our planet over millions of years.

A thorough comparative analysis of geological data from Turkey and China significantly enriches the context of our findings. Turkey's tectonic history, marked by intricate interactions between the Eurasian and Arabian plates, mirrors that of Iran. This is evidenced by the presence of notable ophiolitic remnants and high-pressure metamorphic complexes in both regions. These geological formations underscore the extensive influence of ancient oceanic processes and highlight the interconnected nature of these tectonic settings.

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Additionally, the study's findings reveal that the Proto-Tethys Ocean played a crucial role in the tectonic evolution of these regions. The ocean's opening and closing cycles, along with associated subduction and magmatic activities, significantly influenced the geological development of Iran, Turkey, and China. This shared geodynamic history underscores the interconnectedness of these regions and their collective contribution to the broader narrative of Earth's tectonic evolution.

Furthermore, the study's comparative approach provides a comprehensive understanding of the geological processes that have shaped these regions. By examining the similarities and differences in their tectonic histories, we gain valuable insights into the mechanisms driving continental assembly and rifting. This knowledge not only enhances our understanding of Earth's geological past but also informs future research and exploration efforts.

In conclusion, the comparative analysis of geological data from Turkey and China significantly enriches our understanding of the tectonic evolution of the Iranian plateau. The shared geodynamic history of these regions, shaped by the Proto-Tethys Ocean, highlights the interconnectedness of their geological pasts. This interconnectedness is evident through the presence of similar geological formations, such as ophiolitic remnants and high-pressure metamorphic complexes, which suggest a common tectonic narrative influenced by ancient oceanic processes.

The study underscores the importance of interdisciplinary research and regional tectonic contexts in reconstructing Earth's history. By integrating geological, geophysical, and geochemical data, we can develop a more comprehensive understanding of the complex processes that have shaped our planet over millions of years. This approach not only enhances our knowledge of past tectonic events but also provides valuable insights for future exploration and environmental assessments.

Furthermore, the findings from this study have significant implications for resource exploration.

Understanding the tectonic history and geological evolution of the Iranian plateau, as well as its connections to Turkey and China, can guide the identification of potential mineral deposits and other natural resources. This knowledge is crucial for developing sustainable resource management strategies and ensuring the responsible use of Earth's geological wealth.

In addition to resource exploration, the study's insights into the tectonic evolution of the region can inform environmental assessments and hazard mitigation efforts. By recognizing the geological processes that have shaped the Iranian plateau and its surrounding areas, we can better predict and prepare for natural hazards such as earthquakes and landslides. This proactive approach can help protect communities and infrastructure, ultimately contributing to the resilience and sustainability of the region.

Overall, the comparative analysis of geological data from Turkey and China not only enriches our understanding of the Iranian plateau's tectonic evolution but also highlights the broader significance of interdisciplinary research and regional tectonic contexts. By continuing to explore these connections, we can gain deeper insights into Earth's geological history, inform future exploration efforts, and enhance our ability to manage and protect our planet's natural resources and environments.

## Discussion et Conclusion

Cette étude propose que la suture de l'océan Proto-Téthys à grande échelle se situe le long de la faille actuelle de l'Alborz Nord, qui préserve une gamme de roches métamorphiques de pression moyenne à élevée, y compris celles du complexe de Gasht, de la série précambrienne de Shanderman et des schistes de Gorgan. Les âges magmatiques se regroupant autour de 580-520 Ma suggèrent la nécessité de restaurer la configuration paléogéodynamique de la région. Nos recherches suggèrent l'existence de trois corps océaniques adjacents avec des dynamiques de subduction distinctes : l'océan Proto-Téthys dans le nord de l'Iran et deux arcs arrière en Iran central et dans le domaine du Zagros. La subduction a probablement commencé au Précambrien supérieur dans l'Alborz et l'Iran central, coïncidant avec des vestiges de croûte océanique dans l'Alborz occidental, Anarak, la zone sud de Sanandaj-Sirjan et les régions de Takab.

Le cadre paléogéodynamique reconstruit implique que la fermeture de l'océan Proto-Téthys a conduit à la formation d'un orogène collisionnel, entraînant l'exhumation des roches métamorphiques le long de la faille de l'Alborz Nord. Les signatures géochimiques des roches magmatiques de la région indiquent une origine liée à la subduction, avec la présence de magmas dérivés de la croûte continentale et du manteau. L'évolution tectonique de la région est encore compliquée par la présence de vestiges ophiolitiques, qui suggèrent de multiples épisodes de formation et de destruction de la croûte océanique. Les schistes de Gorgan, en particulier, présentent une signature métamorphique unique, avec des pressions maximales estimées à environ 1,5-2,0 GPa, indiquant une subduction profonde de la croûte continentale.

Nos résultats suggèrent que l'océan Proto-Téthys a joué un rôle crucial dans la formation de l'histoire géologique du nord de l'Iran, la faille de l'Alborz Nord servant de zone de suture majeure qui préserve un enregistrement de la fermeture de l'océan et de l'activité orogénique résultante. De plus, la présence de bassins arrière en Iran central et dans le domaine du Zagros implique une interaction complexe entre la subduction et le rifting continental, ce qui a finalement conduit à la formation du plateau iranien moderne.

Une analyse comparative approfondie des données géologiques de la Turquie et de la Chine enrichit considérablement le contexte de nos découvertes. L'histoire tectonique de la Turquie, caractérisée par des interactions complexes entre les plaques eurasienne et arabe, reflète étroitement celle de l'Iran. Cela est évident par la présence de vestiges ophiolitiques notables et de complexes métamorphiques de haute pression dans les deux régions. Ces formations géologiques soulignent l'influence étendue des processus océaniques anciens et mettent en évidence la nature interconnectée de ces contextes tectoniques.

En Chine, en particulier dans le bloc du Yangtsé, la documentation des processus de subduction liés à l'océan Proto-Téthys révèle des évolutions géologiques parallèles à nos observations en Iran. Les preuves d'événements métamorphiques significatifs et de séquences sédimentaires en Chine s'alignent avec les chronologies tectoniques identifiées sur le plateau iranien. Ces interactions entre les environnements géologiques de l'Iran, de la Turquie et de la Chine soulignent une histoire géodynamique partagée façonnée par l'océan Proto-Téthys. Cette histoire est caractérisée par l'ouverture et la fermeture cycliques des océans anciens, les événements de subduction et les activités magmatiques associées.

Les implications de cette étude vont bien au-delà de la compréhension géologique de l'Iran seul. En explorant les interconnexions entre ces régions, nous dévoilons un récit plus large de l'assemblage continental et du rifting, fortement influencé par les dynamiques océaniques anciennes. Les recherches futures bénéficieront grandement d'investigations supplémentaires sur ces relations, car elles détiennent la clé pour démêler l'évolution géologique complexe de la région. Comprendre l'héritage tectonique partagé de l'Iran, de la Turquie et de la Chine approfondira non seulement notre compréhension de l'histoire de la Terre, mais guidera également les futures explorations minérales et les études environnementales à travers ces paysages historiquement interconnectés.

De plus, cette étude souligne l'importance de considérer les contextes tectoniques régionaux pour saisir pleinement l'évolution géologique d'une zone spécifique. Cette approche peut être appliquée à d'autres régions avec des contextes tectoniques similaires, fournissant des informations précieuses sur leurs histoires géologiques. L'analyse comparative de ces régions met également en évidence la valeur de la recherche interdisciplinaire, qui combine des données géologiques, géophysiques et géochimiques pour reconstruire l'histoire de la Terre et mieux comprendre les processus complexes qui ont façonné notre planète au cours de millions d'années.

En outre, les résultats de l'étude révèlent que l'océan Proto-Téthys a joué un rôle crucial dans l'évolution tectonique de ces régions. Les cycles d'ouverture et de fermeture de l'océan, ainsi que les activités de subduction et magmatiques associées, ont significativement influencé le développement géologique de l'Iran, de la Turquie et de la Chine. Cette histoire géodynamique partagée souligne l'interconnexion de ces régions et leur contribution collective au récit plus large de l'évolution tectonique de la Terre.

En conclusion, l'analyse comparative des données géologiques de la Turquie et de la Chine enrichit considérablement notre compréhension de l'évolution tectonique du plateau iranien. L'histoire géodynamique partagée de ces régions, façonnée par l'océan Proto-Téthys, met en évidence l'interconnexion de leurs passés géologiques. Cette interconnexion est évidente à travers la présence de formations géologiques similaires, telles que les vestiges ophiolitiques et les complexes métamorphiques de haute pression, qui suggèrent un récit tectonique commun influencé par les processus océaniques anciens.

L'étude souligne l'importance de la recherche interdisciplinaire et des contextes tectoniques régionaux dans la reconstruction de l'histoire de la Terre. En intégrant des données géologiques, géophysiques et géochimiques, nous pouvons développer une compréhension plus complète des processus complexes qui ont façonné notre planète au cours de millions d'années. Cette approche non seulement améliore notre connaissance des événements tectoniques passés, mais fournit également des informations précieuses pour les futures explorations et évaluations environnementales.

De plus, les résultats de cette étude ont des implications significatives pour l'exploration des ressources. Comprendre l'histoire tectonique et l'évolution géologique du plateau iranien, ainsi que ses connexions avec la Turquie et la Chine, peut guider l'identification de gisements minéraux potentiels et d'autres ressources naturelles. Cette connaissance est cruciale pour développer des stratégies de gestion durable des ressources et assurer l'utilisation responsable des richesses géologiques de la Terre.

En plus de l'exploration des ressources, les informations tirées de cette étude sur l'évolution tectonique de la région peuvent informer les évaluations environnementales et les efforts de mitigation des risques. En reconnaissant les processus géologiques qui ont façonné le plateau iranien et ses environs, nous pouvons mieux prévoir et nous préparer aux risques naturels tels que les tremblements de terre et les glissements de terrain. Cette approche proactive peut aider à protéger les communautés et les infrastructures, contribuant finalement à la résilience et à la durabilité de la région.

Dans l'ensemble, l'analyse comparative des données géologiques de la Turquie et de la Chine non seulement enrichit notre compréhension de l'évolution tectonique du plateau iranien, mais met également en évidence l'importance plus large de la recherche interdisciplinaire et des contextes tectoniques régionaux. En continuant à explorer ces connexions, nous pouvons obtenir des informations plus approfondies sur l'histoire géologique de la Terre, informer les futurs efforts d'exploration et améliorer notre capacité à gérer et protéger les ressources naturelles et les environnements de notre planète.

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